

## PATENT SPECIFICATION

(11) 1 596 330

- (21) Application No. 23610/78 (22) Filed 26 May 1978  
 (44) Complete Specification published 26 Aug. 1981  
 (51) INT CL<sup>3</sup> F25J 1/02  
 (52) Index at acceptance  
       F4P AB  
 (72) Inventor JACK THOMPSON



## (54) GAS LIQUEFACTION

- (71) We, CONSTRUCTORS JOHN BROWN LIMITED, a British Company, of CJB House, Eastbourne Terrace, Paddington, London W2 6LE, and the BRITISH PETROLEUM COMPANY LIMITED, a British Company of Britanic House, Moor Lane, London EC2 do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—
- The present invention relates to a process for the production of a liquefied natural gas, preferably offshore.
- Offshore gas may be available either from subsea natural gas fields or as associated gas obtained during the course of oil production. The latter may be disposed of in various ways including re-injection to the field, flaring, or pipe lining to land, but often none of these methods is acceptable.
- There has for some time been a need for an alternative method of disposing of offshore natural gas which is acceptable to all the parties involved. It has been suggested that an alternative is to convert the gas to liquefied natural gas (LNG) on the offshore production facilities, but this has its disadvantages, some of which are:
- (i) unacceptable space requirements on platforms,
  - (ii) the difficulties of storage of LNG at sea,
  - (iii) the difficulties of transfer at sea of cryogenic liquids to LNG tankers,
  - (iv) the varying production rate of a field and hence the inability to obtain a good load factor on a natural gas liquefaction plant over the field life, and
  - (v) the difficulty of re-using the capital plant at the end of the field life.
- We have now developed a process which may be used for converting such offshore gas to liquefied natural gas which does not suffer from the above disadvantages and which should be acceptable to all the parties involved. It should be appreciated, however, that the present process is as
- equally applicable to whatever the ship location e.g. dockside use as it is to use offshore.
- According to the present invention, there is provided a process for the production of a liquefied natural gas, which process comprises the steps of: (a) supplying gaseous natural gas to a sea-going vessel which is adapted to store and transport liquefied natural gas, and (b) passing the said gaseous natural gas and a liquefied gas through a heat exchanger situated on board the said sea-going vessel so that the said gaseous natural gas is liquefied and the said liquefied gas is gasified, the said liquefied gas having a boiling point at atmospheric pressure which is lower than the critical temperature of methane.
- As will be appreciated by those skilled in the art, before its liquefaction each gas has to be pretreated to remove therefrom impurities, such as water and carbon dioxide, to an extent which is sufficient to avoid blockages. Desirably, hydrogen sulphide is also removed from natural gas at this pretreatment stage.
- The liquefied natural gas produced by the process according to the present invention may be used to assist by heat exchange in the production of other liquefied gases, such as liquid air or liquid nitrogen, depending on the economics of the situation including the cost of fuel and the ratio of LNG price to gas price.
- According to a further aspect of the present invention, therefore, there is provided a process for the production of liquefied gas, which gas has a boiling point at atmospheric pressure which is lower than the critical temperature of methane, comprising passing through a liquefaction plant, which plant includes a heat exchanging means and is situated on land, a liquefied natural gas produced by the process according to the invention, and the gas to be liquefied.
- Alternatively, the liquefied natural gas may be sold as such.
- Whilst any gas which satisfies the above

criteria can be used at the liquefied gas, in practice the preferred gases are air and nitrogen. It will be seen from the Table below that both air and nitrogen are cold enough at atmospheric pressure to cool methane (which is by far the main constituent of natural gas) to  $-259^{\circ}\text{F}$  and hence liquefy it at atmospheric pressure. Furthermore, both air and nitrogen are readily available, although to produce liquid nitrogen one has to incur the further expense of distilling liquid air. However, liquid air is, in relative terms, more dangerous to use than liquid nitrogen which is non-combustible, although in practice it only becomes dangerous if safety standards are not met. Another advantage of using air or nitrogen is that either may be discharged to the atmosphere after use without pollution problems. This is not so with ethylene, although in practice it would be possible to liquefy natural gas using ethylene under pressure.

TABLE

Gas	Boiling Point at Atmospheric Pressure $^{\circ}\text{F}$	Critical Temperature $^{\circ}\text{F}$
Methane ( $\text{C}_1$ )	-259	-116
Air	-318	-221
Nitrogen	-320	-233
Oxygen	-297	-182
Ethylene	-155	+50

Hereinafter reference will be made to the use of liquid air or liquid nitrogen as the liquefied gas, although such should not be read as limiting the present invention.

In a preferred embodiment, liquid air or nitrogen is produced on shore and transported in a tanker to the field. The tanker is equipped with heat exchangers and other equipment for gas liquefaction. At the field are one or more mooring terminals to which the tanker can be moored and connected to a supply of gas from the production facilities, most probably via a subsea flowline, buoy riser, and loading hose. After mooring, gas is admitted to the liquefaction plant on or in the tanker and liquefied by heat exchange with the liquid air/nitrogen. It is then stored in the cryogenic tanks on the tanker until a full or substantial load is achieved, when the tanker unmoors and returns to port. Here, LNG is discharged, liquid air/nitrogen reloaded, and the cycle re-commenced. By the use of more than one tanker and mooring terminal, continuous gas liquefaction can be achieved by the field.

On the tankers gas purification plant may be installed and also mechanical

refrigeration plant. The latter, by doing some of the "easy" cooling in the liquefaction process can substantially decrease the consumption of liquid air/nitrogen, which is relatively expensive to produce. The particular balance between mechanical refrigeration and cooling by liquid air/ $\text{N}_2$  is determined by a study of the economics of the situation. So that mechanical refrigeration can be used thus, the gas to be liquefied is compressed, preferably to a pressure of about 75 atms. For similar reasons, onshore, air to be liquefied is compressed, preferably to about 25 atms. Typically, the quantity (by weight) of liquid air/ $\text{N}_2$  used is substantially the same as that of the LNG produced.

Reference will hereinafter be made to the accompanying drawings, in which:

Figure 1 is a flow diagram of a typical liquefaction cycle of the present invention;

Figure 2 is a flow diagram of an offshore LNG plant, and

Figure 3 is a flow diagram of an onshore liquid air plant.

In Figure 2, natural gas (100 tons/hr, 25 atms,  $300^{\circ}\text{K}$ ) is passed into a ship along line 1. Some of this gas (7.2 tons/hr) is passed along line 2 to power the compressors, and some (4.3 tons/hr) is passed along line 3 to an adsorbant regeneration zone. The remainder (88.5 tons/hr) is compressed in compressor A (6930 Hp.) to a pressure of 75 atms. and purified by removal therefrom of carbon dioxide and water vapour. The purified gas is passed along line 4 through a first heat exchanger 5 through which air (88.5 tons/hr, 2 atms,  $233^{\circ}\text{K}$ ) travelling along line 6 is being passed. The gas (now at  $285^{\circ}\text{K}$ ) is passed along line 7 into a conventional refrigeration plant where it is cooled by propane to  $240^{\circ}\text{K}$ . The gas is then passed along line 8 through a second heat exchanger 9 through which air (88.5 tons/hr, 2 atms,  $178^{\circ}\text{K}$ ) travelling along line 10 is being passed. The cooled gas ( $220^{\circ}\text{K}$ ) is then passed along line 11 back into the refrigeration plant where it is cooled by ethylene to  $185^{\circ}\text{K}$ . The gas is then passed along line 12 to a third heat exchanger 13 through which liquid air (88.5 tons/hr, 2 atms,  $78^{\circ}\text{K}$ ) is being passed along line 14 from a cryogenic tank (not shown) on board the ship. In the heat exchanger 13 the gas is cooled by the liquid air to  $110^{\circ}\text{K}$  i.e. to below its normal boiling point, and is pumped into atmospheric pressure cryogenic tanks (not shown) on board the ship along line 15. The liquid air which is vaporised in heat exchanger 13 is cold enough for it to assist in the cooling steps in the heat exchangers 5, 9 before being vented to the atmosphere along line 16. The total power of the compressors A, B and C is 28000 hp.

In Figure 3, fresh air (92.8 tons/hr, 1 atm., 300°K) is taken into the plant along line 17 and compressed in compressor D (9300 hp.) to a pressure of 7 atms and then in compressor E (8700 hp.) to 25 atms. The air is then cooled by cooling water in cooler F and purified (purification plant not shown) before being passed along line 18 into a multiple heat exchanger 19. In heat exchanger 19 the air is liquefied under pressure by means of LNG (46.4 tons/hr, 1 atm, 111°K) which enters the heat exchanger 19 along line 20. The natural gas (46.4 tons/hr, 1 atm, 280°K) is passed out of the heat exchanger 19 along line 21 and is compressed in compressor G (10900 hp.) to a pressure of 22 atms. Part of this compressed natural gas (8 tons/hr) is passed along line 22 to power the compressors, and the remainder (38.4 tons/hr) is further compressed in compressor H (2000 hp.) to a pressure of 40 atms and passed from the heat exchanger 19 along line 24 and is flashed twice so that liquid air (92.8 tons/hr, 1 atm, 78°K) emerges along line 25 and is passed to cryogenic storage tanks (not shown). The cold gases from the two flash drums 26 and 27 are used in heat exchanger 28 and 29 to assist in the cooling of the liquid air and are then re-cycled along lines 30 (52 tons/hr, 7 atms 115°K) and line 31 (52 tons/hr, 7 atms, 280°K), and line 32 (30.4 tons/hr, 1 atm, 115°K) and line 33 (30.4 tons/hr, 1 atm, 280°K).

The present invention as exemplified by the above specific embodiments offers the following advantages:—

(i) the natural gas liquefaction plant does not have to be installed on the fixed offshore production facilities;

(ii) most of the machinery and plant is onshore where it is easiest and cheapest to build and operate, i.e. while the refrigeration effect is required offshore it is actually produced onshore.

(iii) by the re-use of the cold of the LNG, energy requirements for production of LNG are minimized.

(iv) the problems of offshore storage and transfer of cryogenic liquids are eliminated.

(v) the facilities can be transferred to other fields for re-use when the field concerned is depleted.

(vi) the scheme can be extended to embrace any number of fields with increased economy in multi-field operation.

Throughout the specification and claims by "natural gas" we intend to cover both gas from a gas well and associated gas resulting from oil production.

#### WHAT WE CLAIM IS:—

1. A process for the production of a liquefied natural gas, which process comprises the steps of: (a) supplying gaseous

natural gas to a sea-going vessel which is adapted to store and transport liquefied natural gas, and (b) passing the said gaseous natural gas and a liquefied gas through a heat exchanger situated on board the said sea-going vessel so that the said gaseous natural gas is liquefied and the said liquefied gas is gasified, the said liquefied gas having a boiling point at atmospheric pressure which is lower than the critical temperature of methane.

2. A process as claimed in claim 1 which is carried out offshore.

3. A process as claimed in claim 1 or claim 2 in which the said liquefied gas is liquid air or liquid nitrogen.

4. A process as claimed in any one of the preceding claims in which the said gaseous natural gas is compressed, and then cooled by mechanical refrigeration, before liquefaction thereof.

5. A process as claimed in claim 4 in which the said gaseous natural gas is compressed to a pressure of about 75 atms.

6. A process as claimed in any one of claims 1 to 5 in which the said liquefied gas has been compressed before liquefaction thereof.

7. A process as claimed in claim 6 in which the said liquefied gas has been compressed to a pressure of 25 atms.

8. A process as claimed in any one of the preceding claims in which the quantity (by weight) of the said liquefied gas used is substantially the same as that of the liquefied natural gas produced.

9. A process for the production of a liquefied natural gas substantially as hereinbefore described with reference to, and as illustrated in, Figure 1 or Figure 2 of the accompanying drawings.

10. A liquefied natural gas which has been produced by a process as claimed in any one of the preceding claims.

11. A natural gas in the gaseous state which has been produced from a liquefied natural gas as claimed in claim 10.

12. A process for the production of a liquefied gas, which gas has a boiling point at atmospheric pressure which is lower than the critical temperature of methane, comprising passing through a liquefaction plant, which plant includes a heat exchanging means and is situated on land, a liquefied natural gas as claimed in claim 10 and the gas to be liquefied.

13. A process as claimed in claim 12 in which the gas to be liquefied is air or nitrogen.

14. A process as claimed in claim 12 or claim 13 in which the gas to be liquefied is compressed before liquefaction thereof.

15. A process as claimed in claim 14 in which the gas is compressed to a pressure of 25 atms.

16. A process for the production of a liquefied gas, which gas has a boiling point at atmospheric pressure which is lower than the critical temperature of methane, substantially as hereinbefore described with reference to, and as illustrated in, Figure 1 or Figure 3 of the accompanying drawings.
17. A liquefied gas which has been produced by a process as claimed in any one of claims 12 to 16.

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BOULT, WADE & TENNANT  
Chartered Patent Agents  
34 Cursitor Street, London  
EC4A 1 PQ

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1981  
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from  
which copies may be obtained.

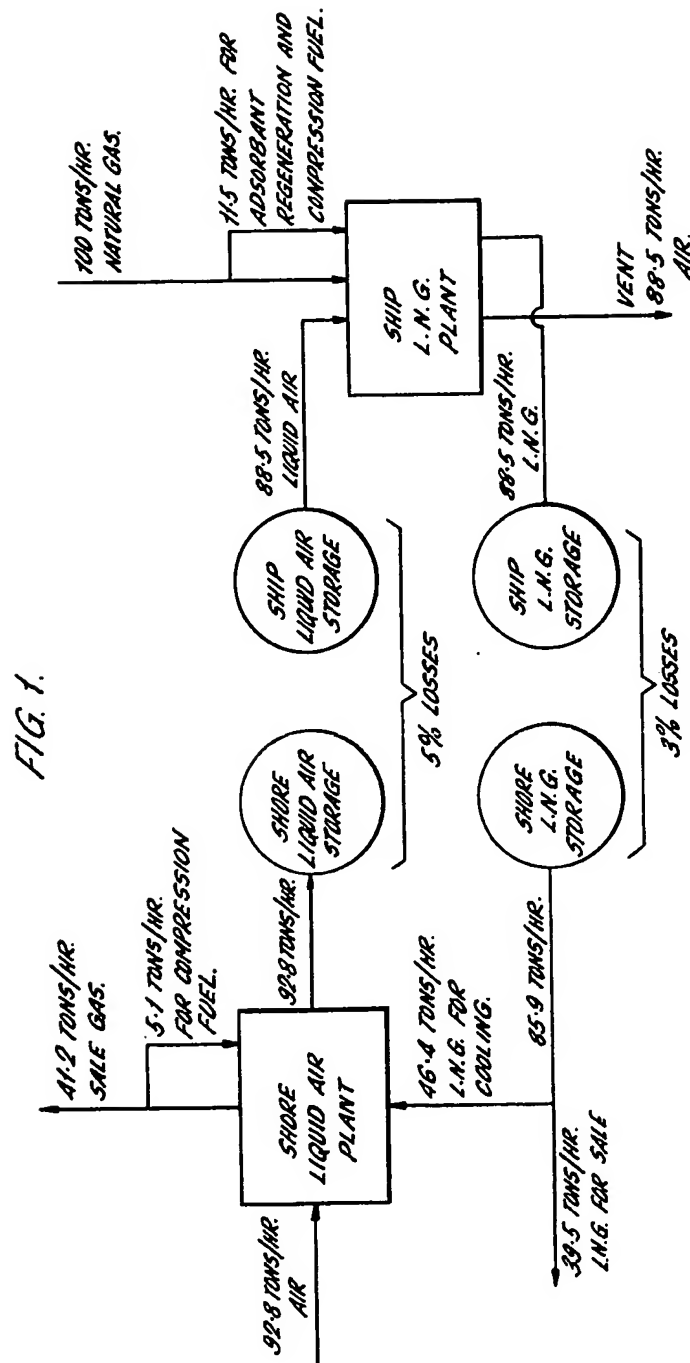


FIG. 2.

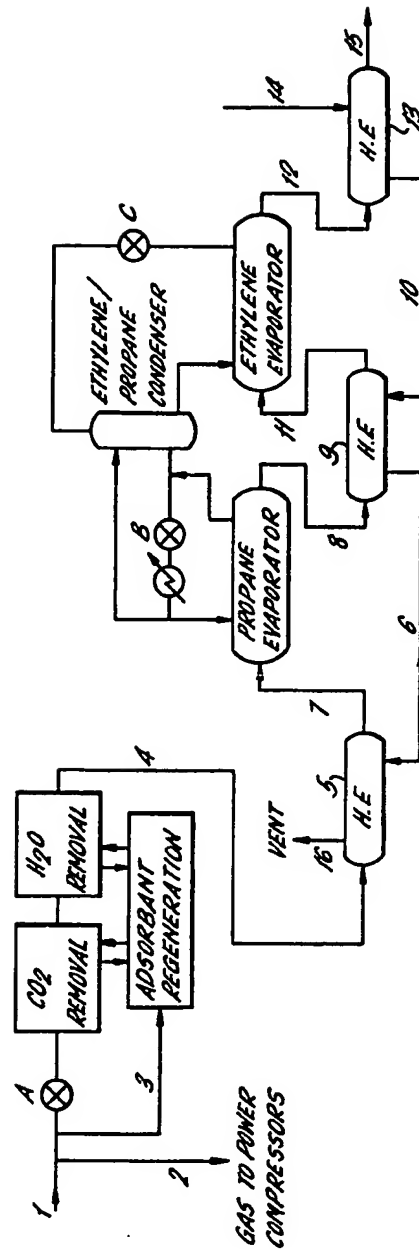


FIG. 3.

